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(71) Applicant *(for all designated States except US)*: **ABB TECHNOLOGY AB** [SE/SE]; S-721 83 Västerås (SE).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **BROGÅRDH, Torgny** [SE/SE]; Plåtverksgatan 140, S-724 79 Västerås (SE).

(74) Agents: **REYIER, Ann-Mari** et al.; Bjerkéns Patentbyrå KB, Box 128, S-721 05 Västerås (SE).

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(54) **Title**: A DEVICE FOR MEASURING TORQUE

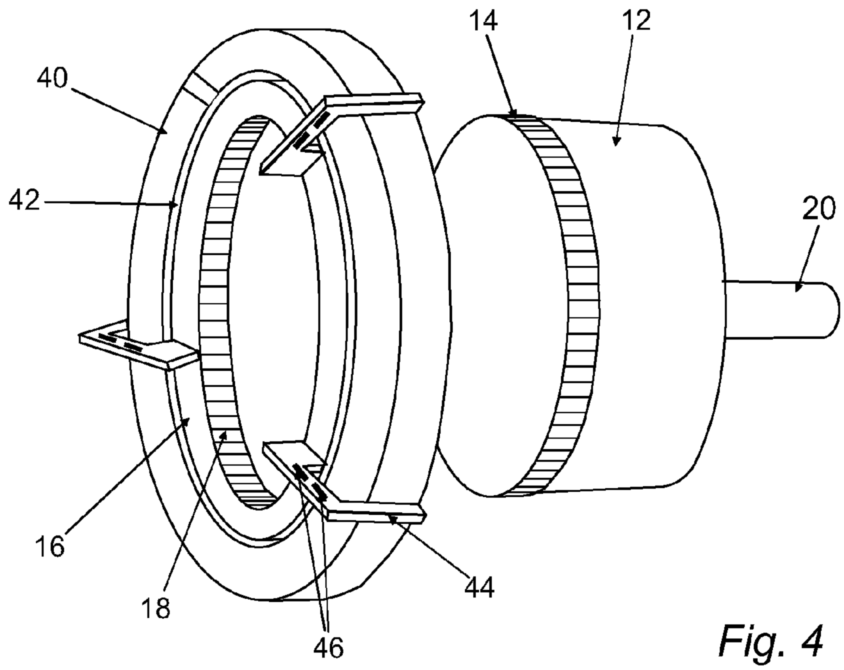

Fig. 4

(57) **Abstract**: The present invention relates to a device for measuring torque transmitted to an output shaft (20) by a harmonic drive gear assembly including a housing (10), a circular spline (16) mounted in the housing, and a flex spline (12) mounted on the output shaft. The device comprises at least one sensor (22a-b) arranged for measuring forces between the circular spline and the housing, and a computing unit configured to receive the measurements from the sensor and, based thereon, to calculate the transmitted torque.

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A DEVICE FOR MEASURING TORQUE

FIELD OF THE INVENTION

The present invention relates to a device for measuring torque transmitted to an output shaft by a harmonic drive gear assembly. Further, the invention relates to the use of such a device for measuring the torque transmitted to an output shaft by a harmonic drive gear driven by a synchronous motor. The present invention further relates to the use of such a device for measuring the torque transmitted to an output shaft of a harmonic drive gear connected to an arm of an industrial robot.

The invention is also useful in other types of applications in which it is of interest to measure the torque transmitted to an output shaft by a harmonic drive gear, such as CNC machines, airplanes, and industrial process control equipment.

PRIOR ART

In order to obtain a much larger use of industrial robots a new robot generation is needed. These robots must have such a high safety that they can work in direct interaction with people not only during programming but also during program execution. It is however difficult to obtain high performance and simultaneously a cost-effective design of a robot of the next generation. What is needed is a robot with high human-robot capability, high industrial performance, and a low cost level. Very important for such a robot is of course the performance and cost of the mechanical and electromechanical components. One of the most critical components in this respect is the speed reducer, and in order to obtain a high torque in relation to weight at high gear ratios the only solution today is to use a harmonic drive gear.

A harmonic drive gear is typically used for high gearing reduction. Very high gear reduction ratios are possible in a small volume and at very low weight. The mechanism has three basic components: a wave generator, a flex spline, and a circular spline. The wave generator has an elliptic shape. The flex spline is like a shallow cup. The sides of the cup are thin, which results in significant flexibility of the walls and low stiffness of the gear. Teeth are positioned radially around the outside of the flex spline. The flex spline fits tightly over the wave generator, so that when the wave generator is rotated, the flex spline deforms to the shape of a rotating ellipse but does not rotate with the wave generator. The circular spline is a rigid circular ring with teeth on the inside. The flex spline and wave generator are placed inside the circular spline, meshing the teeth of the flex spline and the circular spline. Because the flex spline has an elliptical shape, its teeth only actually mesh with the teeth of the circular spline in two regions on opposite sides of the flex spline. The key to the design of the harmonic drive is that there are fewer teeth on the flex spline than there are on the circular spline. This means that for every full rotation of the wave generator, the flex spline rotates a slight amount backward relative to the circular spline. Thus the rotation action of the wave generator results in a much slower rotation of the flex spline in relation to the circular spline.

The harmonic drive gear further includes a housing. The circular spline is mounted in the housing and thus the flex spline rotates relative the housing. In the robot case, a motor shaft is connected to the wave generator and the flex spline is mounted to an output shaft that is connected to the robot arm.

However, the harmonic drive gear is very compliant compared to other compact gear boxes, giving the robot low stiffness and a low mechanical bandwidth. One way to improve this situation is to introduce torque sensors on the output shafts of the harmonic drive gear and include a torque feedback in a model-based controller. This has been made in order to make the robot more robust and sensitive at interactions and in order to increase the safety of the robot by sensor redundancy. The torque sensors used are of a traditional wheel type with three beams having at least one strain gauge each.

Figure 1 shows an outline of a state of the art torque sensor 1 for measurements of torque transmitted to an output shaft. The output shaft is divided into two sections 2a and 2b, and the torque sensor is arranged between the two shaft sections. For the robot application discussed in the introduction, the shaft section 2a is driven by the low speed side of a harmonic drive gear and the shaft section 2b is connected to a robot arm. The torque sensor 1 includes an outer ring 4 mechanically connected to the shaft section 2a and an inner ring 5 mechanically connected to the shaft section 2b. The inner and outer rings are connected to each other via three beams 6 provided with strain gauges 7. When a torque is transmitted through the sensor the beams 6 will bend and the strain gauges 7 will measure a strain which is proportional to the shaft torque and thus the torque from the gear. The main shortcomings of this measurement system are:

1) It adds weight and space when integrated into a lightweight servo actuator for a lightweight robot.
2) The cables to the strain gauges must wind up on the shaft, which limits the number of turns that the shaft can be rotated and which also reduces the reliability of the robot.
3) At overload, for example in a collision between the robot arm and its surroundings, torque transients can destroy the strain gauges and the transducer structure.
4) The two shaft sections must be accurately in line to avoid cyclic disturbance stress on the strain sensors and thus measurement disturbance.

5) The sensor assembly is costly to manufacture.

OBJECTS AND SUMMARY OF THE INVENTION

The object of the present invention is to provide an improved device for measuring torque transmitted to an output shaft by a harmonic drive gear, which alleviated the drawbacks mentioned above.

This object is achieved by a device as defined in claim 1.

The invention is characterized in that the device comprises at least one sensor arranged for measuring forces between the circular spline and the housing, and a computing unit configured to receive the measurements from the sensor and, based thereon, to calculate the transmitted torque.

According to the invention at least one force sensor is integrated into the harmonic drive gear. Further, the sensor is integrated into the stationary side of the harmonic drive gear. This will give the following advantages over the prior art torque measurement device: lower cost, more robust, more compact actuator, measurements at an infinite number of shaft revolutions are possible, and the device can easily be combined with a torque limiter.

According to an embodiment of the invention, the device comprises at least one connecting element arranged between the circular spline and the housing and the sensor is positioned on the connecting element. One end of the connecting element is directly or indirectly mechanically connected to the circular spline and the opposite end is directly or indirectly mechanically connected to the housing. The connecting element will be exerted to strain because of the torque transmitted from the housing to the flex spline and then to the output shaft. The connecting element is equipped with at least one sensor which makes it possible to measure the transmission of torque between the circular spline gear teeth and the flex spline gear teeth.

According to an embodiment of the invention, the device comprises at least three sensors arranged for measuring the force between the circular spline and the housing and at least three connecting elements arranged between the circular spline and the housing, and each connecting element is provided with at least one of said sensor. This embodiment with at least three sensors makes the torque measurement more accurate. With two sensors on each connecting element, it will be possible to measure six degrees of freedom, three force components and three torque components of the transmission between the circular spline gear teeth and the flex spline gear teeth.

According to an embodiment of the invention, the sensor is a strain gauge arranged for measuring strains between the circular spline and the housing. Stain gauges are made of metal or semiconductor material, and are standard for this type of measurement.

According to an embodiment of the invention, the device comprises a bearing ring fixedly connected to the housing and arranged between the circular spline and the housing, and said sensor is arranged for measuring tangential forces between the circular spline and the bearing ring. This bearing ring is also beneficial to absorb the radial force radiation generated by the wave generator and that may disturb the measurement at least at low rotational speeds.

According to an embodiment of the invention, at least one connecting element including said sensor is arranged between the circular spline and the bearing ring, and the connecting element is connected to the circular spline via an overload release element arranged to mechanically disconnect the circular spline from the bearing when the transmitted torque is larger than a mechanically predefined value. In this way an industrial robot can be intrinsically safe and not harmful in case of collisions and clamping.

According to an embodiment of the invention, the overload release element comprises a mechanical coupling for coupling to the circular spline and a spring acting on the mechanical coupling, and the spring constant is selected such that the mechanical coupling will be released when the transmitted torque is larger than said mechanically predefined value.

According to an embodiment of the invention, the harmonic drive gear assembly includes a rotatable wave generator, the device comprises a compensation module including a table with compensation values for compensation of torque ripple caused by the wave generator rotation, and the compensation values are stored as a function of the motor angle, the compensation table is configured to receive measured values of the motor angle and to select a compensation value in dependence on the motor angle, and the computing unit is configured to receive the compensation value and to subtract the compensation values subtracted from calculated transmitted torque to form torque values. An advantage of this embodiment is that it makes it possible to use a compliant circular spline which reduces the weight of the gear assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained more closely by the description of different embodiments of the invention and with reference to the appended figures.

Fig. 1 shows a prior art device for measuring torque transmitted to an output shaft.

Figs. 2a-b show a device for measuring torque transmitted to an output shaft according to a first embodiment of the invention.

Fig. 3 shows a device for measuring torque transmitted to an output shaft according to a second embodiment of the invention.

Fig. 4 shows a device including a bearing for measuring torque transmitted to an output shaft according to a third embodiment of the invention.

Fig. 5 shows an example of a device for measuring torque including a torque limiter.

Fig. 6 shows the harmonic drive concept integrated in a special motor concept to obtain a magnetically driven wave generator.

Fig. 7 shows an example of a device for measuring torque of a harmonic drive integrated in a special motor concept to obtain a magnetically driven wave generator.

Fig. 8 shows a device for measuring torque transmitted to an output shaft according to another embodiment of the invention with a circular spline inside the flex spline.

Fig. 9 shows an example of how a device for measuring torque can be used in a servo actuator with a magnetically driven wave generator with a circular spline inside the flex spline.

Fig. 10 shows an example of how torque disturbances can be electronically compensated.

Fig. 11 outlines the integration of a low cost capacitive encoder into a servo actuator.

Fig. 12 exemplifies electrode patterns that can be used on encoder rings.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Figure 1 shows a prior art device for measuring torque transmitted to an output shaft as described above.

Figures 2a-b shows a device for measuring torque according to an embodiment of the invention. The device is integrated into a harmonic drive gear assembly. The device and the harmonic drive gear assembly are mounted in a gear box housing 10. Figure 2a shows the device and harmonic drive gear assembly inside the housing 10, and figure 2b shows an exploded view of the device and harmonic drive gear assembly without the housing. The harmonic drive gear assembly has three basic components: a wave generator (not shown), a flex spline 12 provided with gear teeth 14, and a circular spline 16 provided with gear teeth 18. The wave generator is arranged to rotate with high speed and is driven by a motor. The flex spline 12 fits tightly over the wave generator, so that when the wave generator is rotated, the flex spline deforms to the shape of a rotating ellipse but does not rotate with the wave generator. The flex spline 12 and the wave generator are placed inside the circular spline 16, meshing the teeth of the flex spline and the circular spline. The flex spline 12 is mounted to an output shaft 20, which for example is connected to a robot arm.

The device is configured to measure the torque transmitted to the output shaft 20 of the harmonic drive gear via the flex spline 12. The device comprises at least one sensor arranged for measuring forces between the circular spline 16 and the housing

10. The forces measured are tangential, axial and/or radial forces. In the example shown in figure 2a-b, the device comprises six sensors 22a, 22b arranged for measuring the force between the circular spline 16 and the housing 10. The sensors are, for example, strain gauges. The device further comprises a computing unit 23 configured to receive the measurements from the sensor and, based thereon, to calculate the transmitted torque. The computing unit can be any type of unit capable of executing mathematical calculations, such as a processor or an FPGA. In the case of an industrial robot, the robot controller can be used as the computing unit. The calculations used for determining the torque based on the received measurements are the same as used in a state of the art six-degrees-of-freedom force sensor. The measurement of the six strain gauge resistances gives six signals that are transformed by a calibration matrix to three force components and three torque components. The torque component equal to the transmitted gear torque is used for control of the motor. Other components can be used for fault detection and diagnosis. In the case of three sensors, the measured signals can be averaged to obtain the torque.

In this example the device includes three connecting elements 24 in the form of beams arranged between the circular spline 16 and the housing 10. The sensors 22a, 22b are positioned on the beams 24. The beams 24 are on one side mounted on the gear box housing 10 and on the opposite side mounted on the circular spline 16. The beams 24 will bend because of the torque transmitted from the housing 10 to the flex spline 12 and then to the output shaft 20. As seen in figure 2a, the circular spline 16 is part of the torque measuring device, but of course an extra ring for the beams 24 can be mounted on the circular spline. However, this will give a less weight effective solution. In the figure, each beam 24 is equipped with two strain gauges 22a and 22b, which means that it will be possible to measure all six degrees of freedom (3 force components and 3 torque components) of the transmission between the circular spline gear teeth 18 and the flex spline gear teeth 14.

With a rigid and stiff circular spline ring 16, the pulsating forces from the wave generator (not shown in the figure) will be possible to reduce significantly since the deformation of the circular spline ring will then be negligible. It should be emphasized that the wave generator generates two forces 180 degrees separated and these forces will be internal in the circular spline ring without any need to be transmitted to the gear box housing 10. Thus, with a rigid circular spline only three sensors mounted as 22b are needed, and with a symmetric design it will even be possible to use only one sensor, such as a strain gauge, in a bridge with a non-stressed sensor, such as a strain gauge, for temperature compensation. Instead of strain gauges it is possible to use other sensors to measure forces between the circular spline and the gear box housing. Examples of such sensors are capacitive, magnetostrictive, piezoelectric, and inductive sensors.

Figure 3 shows a variant of the arrangement of the connecting elements 30 joining the circular spline 16 with the gear box housing (not shown in the figure). The connecting elements 30 are elongated and form cantilevers. The connecting elements 30 are in this case adapted to the measurement of torque when having a rigid circular spline 16. Two sensors 32, such as strain gauges, are mounted for sensing the bending of the connecting elements 30 and the connecting elements have a shape that reduces the sensitivity of the strain gauge with respect to the radial forces from the wave generator.

In order to further increase the stiffness of the circular spline assembly with respect to the forces from the wave generator, and to also take care of other parasitic forces on the elements with the strain gauges, a solution where the circular spline 16 is integrated with a bearing 40 can be used. Figure 4 shows the circular spline 16 as an inner ring being connected by means of bearing balls or bearing cylinders to an outer bearing ring 40. There is a gap 42 between the inner ring 16 and the outer ring 40, which can thus rotate in relation to each other. The circular spline ring 16 and the outer ring 40 together form a bearing. Connecting elements 44 with sensors 46, such as strain gauges, are mounted between the circular spline ring 16 and the outer ring 40. One end of the connecting element 44 is fixedly connected to the circular spline ring 16 and the other end is fixedly connected to the outer ring 40. The sensors 46 are arranged for measuring tangential forces between the circular spline and the bearing ring.

The outer ring 40 is fixedly connected to the gear box housing (not shown in the figure). Thus, with a sufficiently high stiffness of the bearing, the connecting elements 44 need only to transmit the gear output torque and the strain gauges 46 will measure only the gear output torque without any disturbance from the wave generator or from residual forces because of friction between the gear teeth 18 and 14. It should be emphasized that it is still important to mount the circular spline in such a way that vibrations will be avoided in the harmonic drive gear. This means that the circular spline assembly is not fixed to the gear box housing until the motor rotates, the wave generator giving the circular spline a neutral position.

Figure 5 shows an example of a device for measuring torque including a torque limiter. Using a bearing for the circular spline as in figure 4 gives the possibility to introduce a torque limiter as outlined in figure 5. In this example, the torque limiter includes an overload release element 50 that is integrated with a connecting element 52 joining the circular spline ring 16 and the outer bearing ring 40. The connecting element 52 is connected to the circular spline 16 via the overload release element 50. The overload release element 50 is arranged to mechanically disconnect the circular spline 16 from the outer bearing ring 40 when the transmitted torque is larger than a mechanically predefined value. The overload release element 50 comprises a mechanical coupling for coupling to the circular spline. The mechanical coupling includes a ball 54 and the circular spline is provided with a groove 56 designed for receiving the ball. The ball 54 is mounted on a pin 58, which can slide in a hole on the connecting element 52.

The overload release element 50 further comprises a spring 56 acting on the ball 54. The spring constant for the spring 56 is selected such that the mechanical coupling will be released when the torque transmitted from the circular spline 16 to the outer bearing ring 40 is larger than the mechanically predefined value. Thus, when the outgoing torque from the harmonic drive exceeds a certain level, the force on the ball 54 will be high enough to compress the spring 56, releasing the ball 54 from the groove 56 in the circular spline 16. The force measurement is, for example, made with a strain gauge 59. The bearing comprises an inner bearing ring in the form of the circular spline 16, an outer bearing ring 40, and a ball 60 arranged between the inner and outer bearing ring. The outer bearing ring 40 is fixed to the gear box housing (not shown). The gear teeth of the circular spline 16 are made directly on the inner surface, but could of course be made on a separate ring mounted on the bearing.

Figure 6 shows the harmonic drive concept integrated in a special motor generating a rotating magnetic field that deforms a magnetic wave generator. Such a motor is known from the patent US005497041. A wave generator 70 is composed of a compliant ring with magnets and between this ring and a stator coil setup 72 a circular spline 74 and a flex spline 75 are mounted. The stator coil setup 72 will generate a rotating magnetic field, which will change the shape of the compliant ring 70 giving a magnetically driven wave generator. The advantage with this concept is that it is possible to obtain a very compact servo actuator since no motor shaft is needed. The problem is that it will not be possible to use any resolver or encoder to obtain a feed-back from the high speed side to the motor control. However, using a circular spline with integrated torque measurements, torque feedback control will be possible for this extremely compact and robust actuator type.

Figure 7 shows one solution to this problem where the circular spline arrangement of figure 3 is used in a servo actuator design based on the same idea as in figure 5. Figure 7 shows a cross section through a servo actuator including an electromagnetically directly driven harmonic drive gear assembly. Magnets 80 are mounted on the inside of a flex spline 12 and an inner stator 82 generates a rotating magnetic field to obtain wave generator movements of the magnets 80. The circular spline 16 is fixed via beams 30 to a housing 84 of the servo actuator, and sensors 32, such as strain gauges, are connected to a computing unit (not shown) via wires 86. Since no high speed shaft is needed, only bearings 88 for the low output speed are needed. In applications where the shaft angle accuracy is important a capacitive encoder 90 can be added. The harmonic drive gear assembly is mounted on a hollow output shaft 91 having a face plate 92 for mounting to the part that is driven by the servo actuator.

Figure 8 shows that it will also be possible to integrate the torque measuring device according to the invention with a circular spline arrangement (98 or 99) when the circular spline is inside the flex spline. The upper left drawing shows a circular spline 100 with outer gear teeth 104 and connecting elements 106 including sensors 108, such as strain gauges. Further strain gauges 109 are arranged on the inside of the circular spline 100. The strain gauges 109 are optional to measure the angle of the wave generator, which is interesting using a magnetic wave generator as in figures 7 and 9. The strain gauges 109 will measure the angle of the magnetic wave generator, which can be use for a servo loop of the high speed side of the gear box. The lower left drawing shows the arrangement with the sensors mounted on connecting elements 110 connecting the outer circular spline ring 102 with an inner ring 112 connected to the gear box housing. In the right figure the circular spline arrangement 99 is shown inside the flex spline 12. The flex spline 12 has in this case inner gear teeth, which are not shown in the figure.

Figure 9 shows how circular spline assemblies 98 and 99 can be used in a servo actuator with a magnetically driven wave generator. In the right figure the circular spline assembly 98 is inserted inside the flex spline 12. In this case magnets 128 deforming the flex spline are mounted on the outside of the flex spline 12. To hold the magnets on the flex spline high strength Kevlar can be used. The wave motion of the flex spline 12 is obtained by means of a rotating magnetic field generated by the stator 124. A circular spline 104 is mounted on the gear box housing 84 via connecting elements 130 containing sensors 108, such as strain gauges. 120 and 121 are low speed bearings, 90 a capacitive high resolution encoder and 122 the mounting flange of the servo actuator.

Figure 10 shows an example of how torque disturbances can be electronically compensated. The main disturbance on the strain measurements is the radial force pulsations generated by the wave generator at a frequency of two times the revolution rate. To compensate for this disturbance, either a filtering can be made, or the modeled torque error can be subtracted from the calculated torque. The strain gauges 22 are connected to a measurement unit 202 including an A/D converter. The measurement unit sends the measurement values of the resistances to a computing unit 204, which includes a calibration table used to calculate the transmitted torque Tcalc. The torque ripple caused by the wave generator rotation is stored in a compensation table 208. Compensation values Tcomp are selected as a function of the motor angle Am, which is measured by a resolver or an encoder or is predicted from the motor current control. The motor angle Am is the same as the wave generator angle. The compensation values Tcomp are subtracted from calculate transmitted torque Tcalc to form torque values Tcontrol used for the motor control. The values in the compensation table 208 are obtained when calibrating the actuator. This calibration can be made by system identification methods, or simply by logging the calculated torque Tcalc at constant torque when the motor shaft is turned at least one revolution.

In high performance applications torque feedback will not be enough since this will not give the positioning accuracy needed in such applications as laser cutting, measurements, deburring, machining, assembly etc. In these applications high precision angle measurements on the low speed side of the actuator can be used as a complement to the torque measurements. Thus, Figure 11 outlines the integration of a low cost capacitive encoder into the servo actuator. In order to obtain as high accuracy as possible with a capacitive encoder it is of outmost importance to mount the encoder rings with high precision and as close to each other as possible. Since the bearing 800 controls the accuracy of the rotation of the flex spline and the assembly flange the idea in figure 11 is to make use of the precision of a bearing 800 for the mounting of capacitive encoder rings. Thus, the ring 940 with the transmitter electrodes is mounted on the outer bearing ring and the ring 950 with the receiver electrodes is mounted on the inner bearing ring via a distance precision element 960. The precision element 960 determines the distance between the encoder rings, which should be less than 25 micrometers. The receiver signals are connected to the measurement electronics via large surface electrodes on the rotating encoder ring 970 and the fixed transmission ring 970. The electrode ring 970 is hold by the ring 980. Between the tool flange 1000 and the encoder protection 930 there is a sealing 990. In this servo actuator design a cable protection tube 720 is fixed to the output flange and rotates via the bearing 735 relative the housing 710.

Figure 12 exemplifies electrode patterns that can be used on the encoder rings. Thus, the transmitter electrodes 1020 connected to the transmitter phases (r,s,t) via the lines 1050, 1060 and 1070 are located on the fixed transmitter encoder ring 940. The encoder ring 950 is equipped with the electrodes 1010, all connected to the line 1030 and the large surface electrode 1040 transmitting the received signals to the transmission ring 970 having an identical electrode as 1040. For simplicity the electrode pattern has been drawn as for a linear encoder. Of course the electrodes form a circular ring pattern on the encoder rings and the electrodes are situated on the surfaces of the rings facing each other.

CLAIMS

1. A device for measuring torque transmitted to an output shaft (20) by a harmonic drive gear assembly including a housing (10;84), a circular spline (16) mounted in the housing, and a flex spline (12) mounted on the output shaft, **characterized in** that the device comprises at least one sensor (22a-b;32;46;59) arranged for measuring forces between the circular spline and the housing, and a computing unit (23) configured to receive the measurements from the sensor and, based thereon, to calculate the transmitted torque.

2. The device according to claim 1, wherein the device comprises at least one connecting element (24;30;44;52) arranged between the circular spline and the housing and the sensor is positioned on the connecting element.

3. The device according to claim 1 or 2, wherein the device comprises at least three sensors (22a-b;32;46;59) arranged for measuring the force between the circular spline and the housing and at least three connecting elements (24;30;44;52) arranged between the circular spline and the housing at a distance from each other, and each connecting element is provided with at least one of said sensors.

4. The device according to any of the previous claims, wherein said sensor is a strain gauge arranged for measuring strains between the circular spline and the housing.

5. The device according to any of the previous claims, wherein the device comprises a bearing ring (40) fixedly connected to the housing and arranged between the circular spline (16) and the housing (84), and said sensor (32) is arranged for measuring tangential forces between the circular spline and the bearing ring.

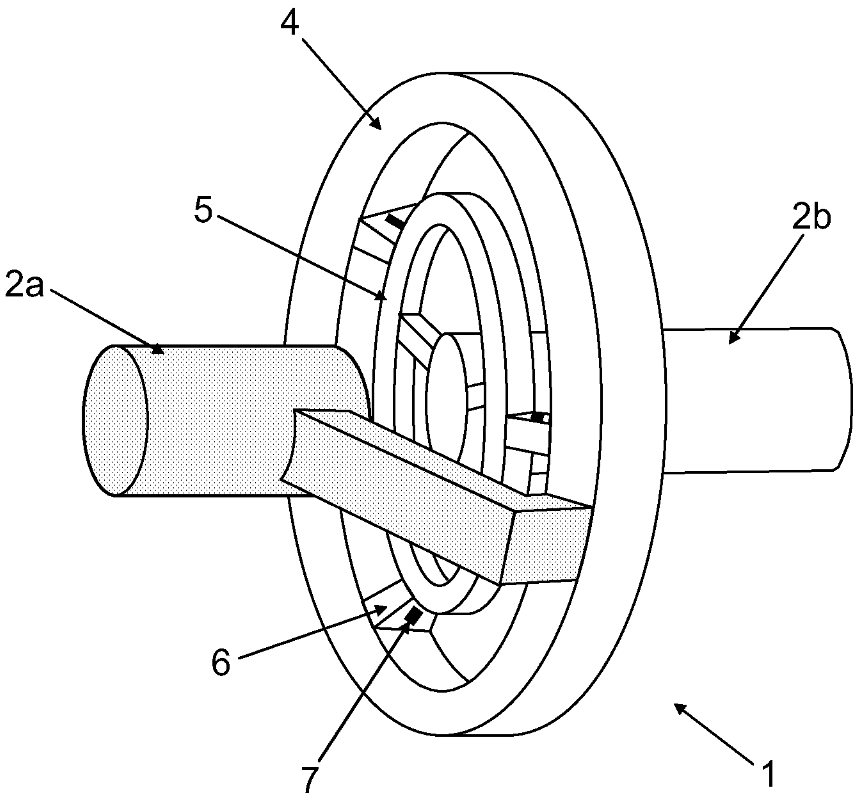
6. The device according to claim 5, wherein at least one connecting element (52) including said sensor (59) is arranged between the circular spline (16) and the bearing ring (40), and the connecting element is connected to the circular spline via an overload release element (50) arranged to mechanically disconnect the circular spline from the bearing ring when the transmitted torque is larger than a mechanically predefined value.

7. The device according to claim 6, wherein the overload release element (50) comprises a mechanical coupling (54, 56) for coupling to the circular spline (16) and a spring (56) acting on the mechanical coupling, and the spring constant is selected such that the mechanical coupling will be released when the transmitted torque is larger than said mechanically predefined value.

8. The device according to any of the previous claims, wherein the harmonic drive gear assembly includes a rotatable wave generator (70), the device comprises a compensation module (208) including a table with compensation values (Tcomp) for compensation of torque ripple caused by the wave generator rotation and the compensation values are stored as a function of the motor angle, the compensation table is configured to receive measured values of the motor angle and to select a compensation value in dependence on the motor angle, and the computing unit (23) is configured to receive the compensation value and to subtract the compensation values subtracted from calculated transmitted torque (Tcalc) to form torque values (Tcontrol).

9. Use of the device according to any of the claims 1 – 8 for measuring the torque transmitted to an output shaft by a harmonic drive gear driven by a synchronous motor.

10. Use of the device according to any of the claims 1 – 8 for measuring the torque transmitted to an output shaft of a harmonic drive gear connected to an arm of an industrial robot.



PRIOR ART

Fig. 1

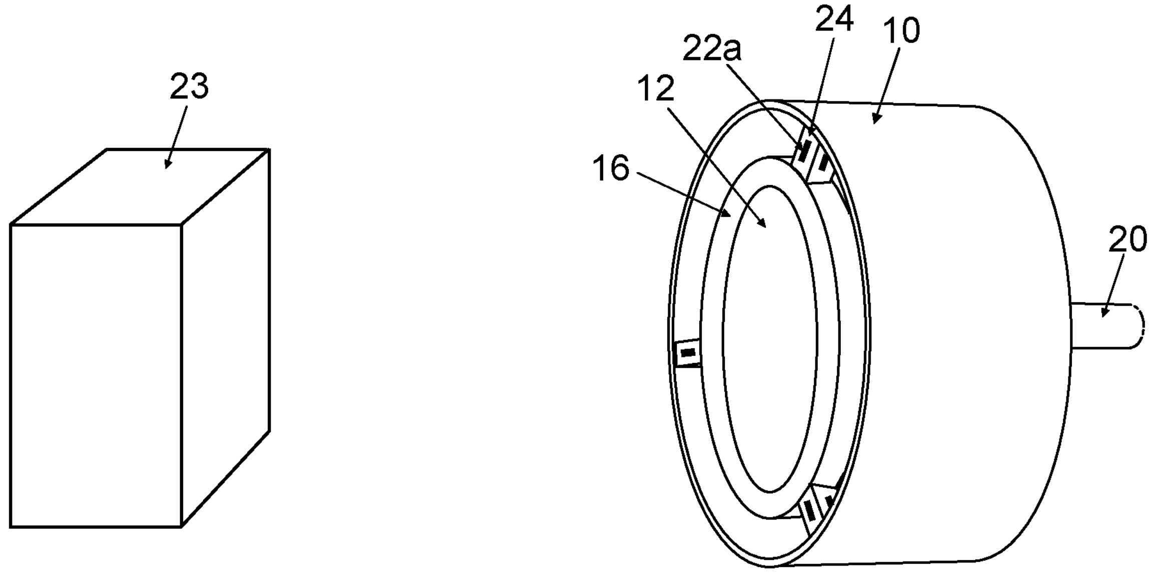


Fig. 2a

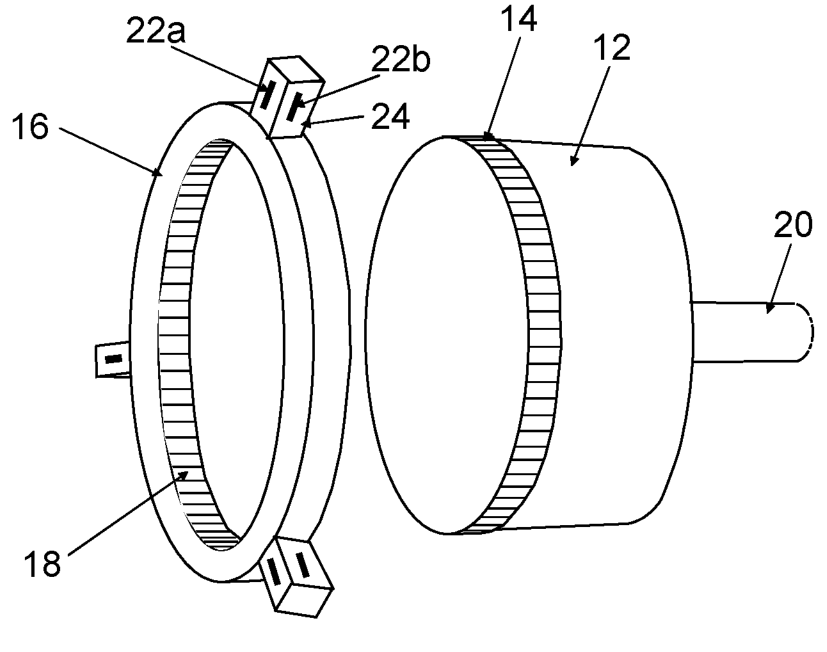


Fig. 2b

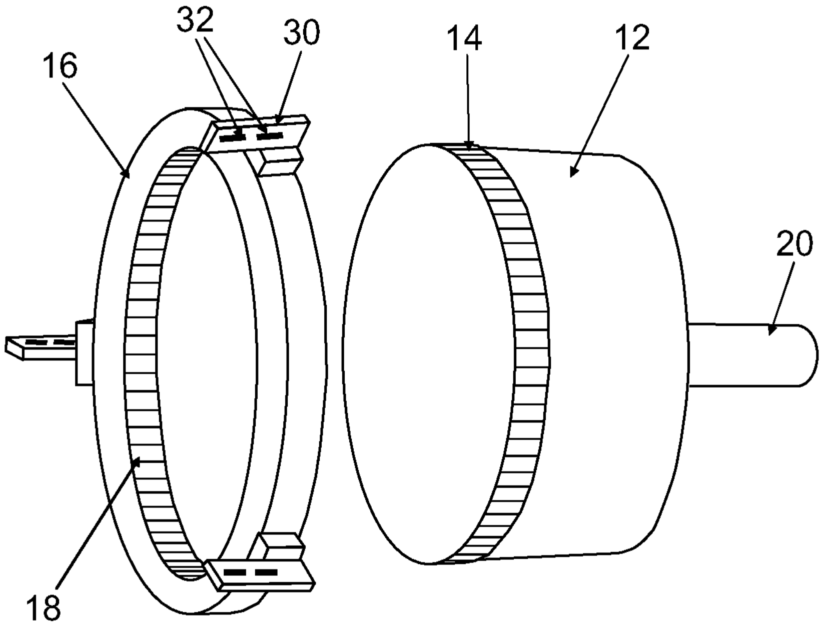


Fig. 3

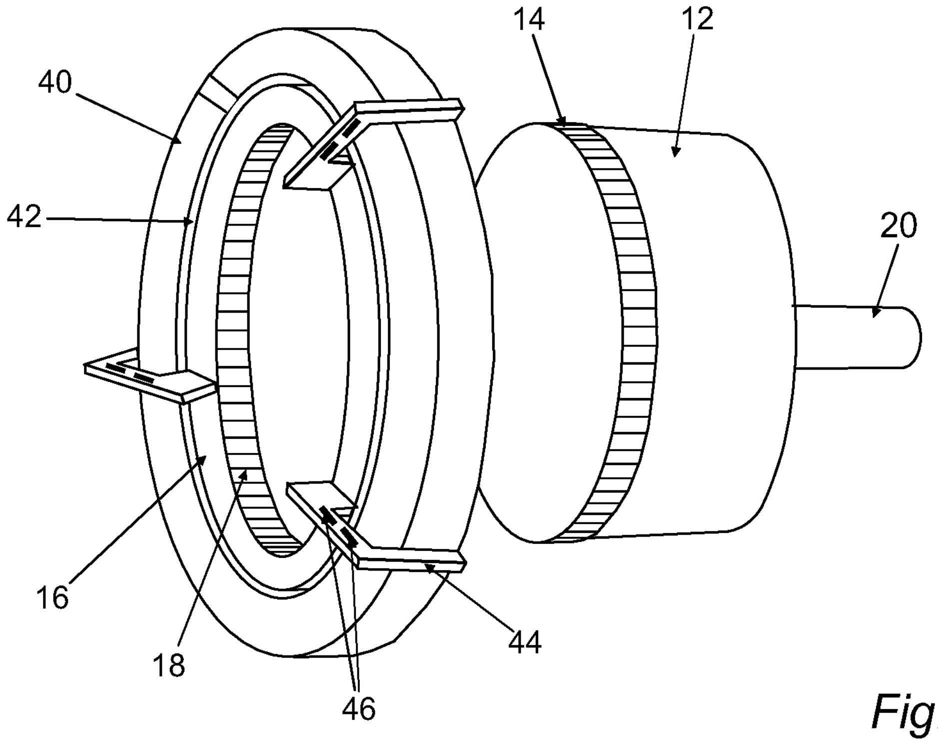


Fig. 4

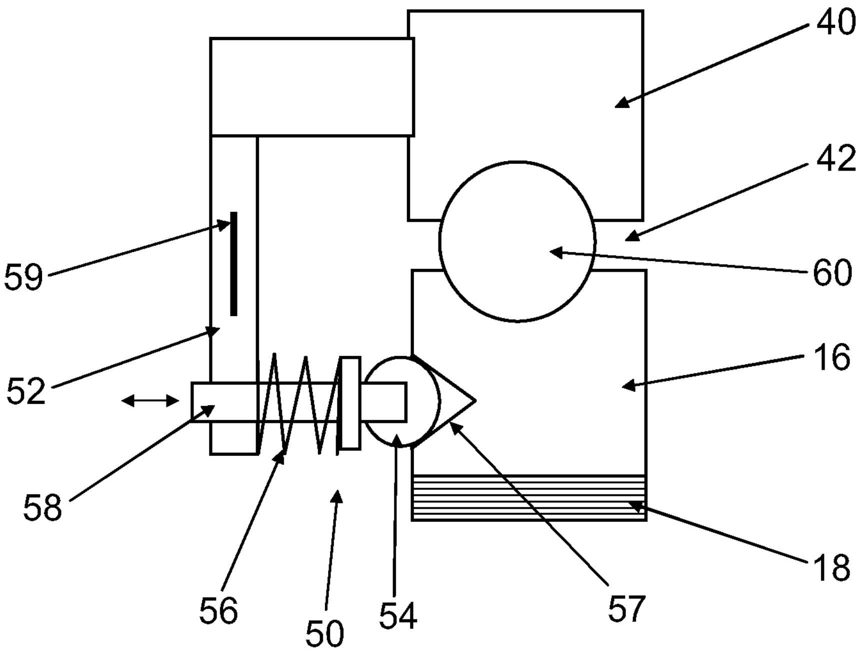


Fig. 5

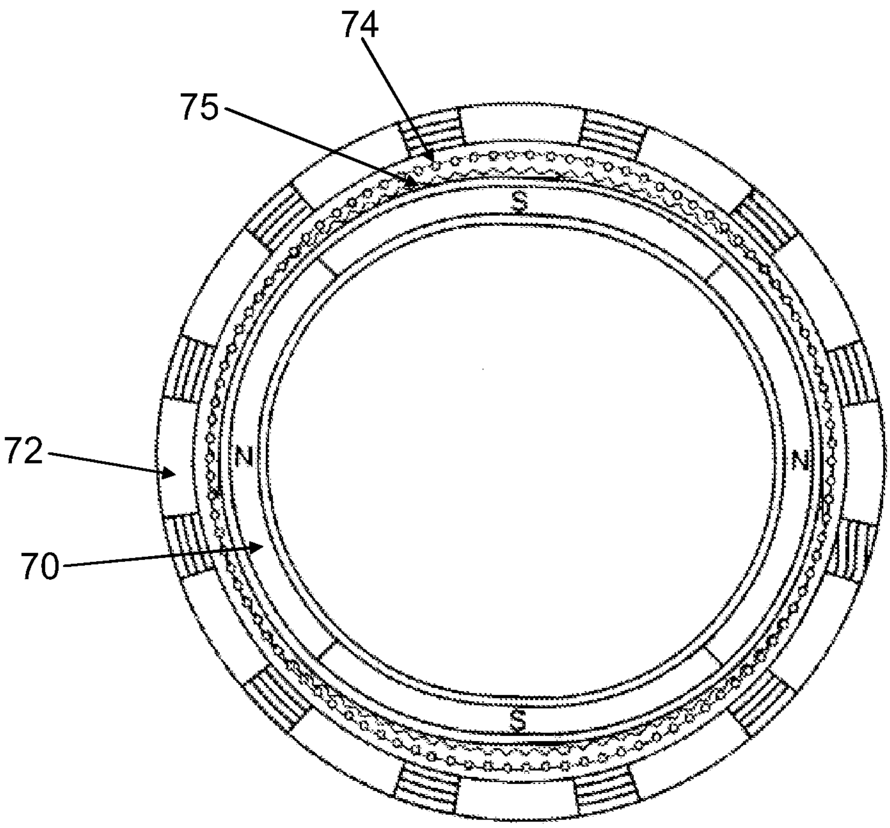


Fig. 6

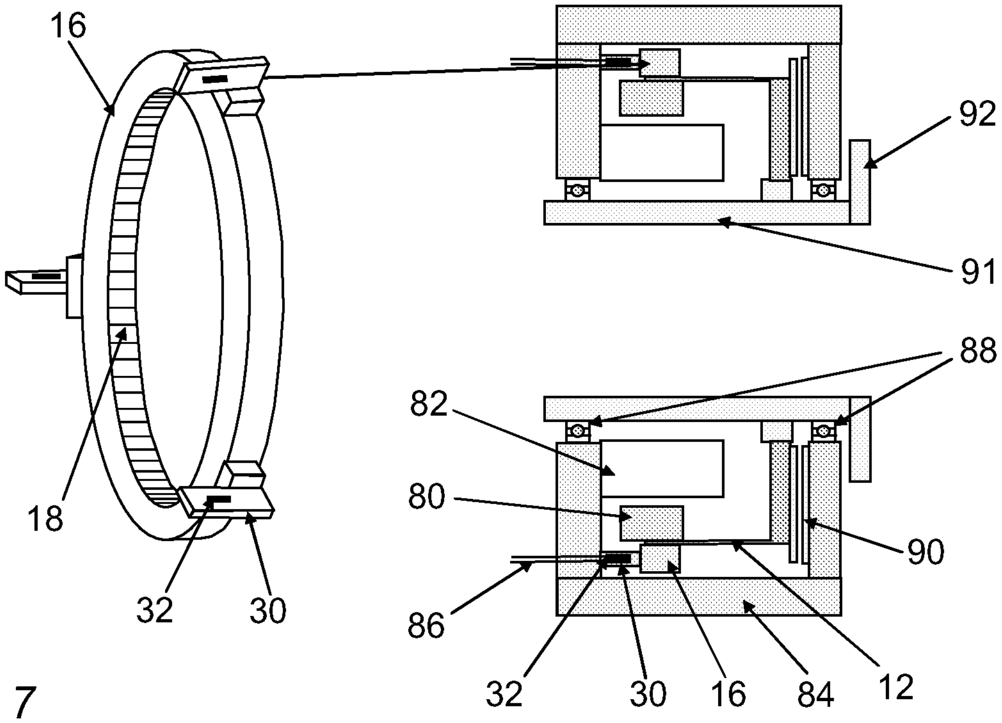

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Fig. 7

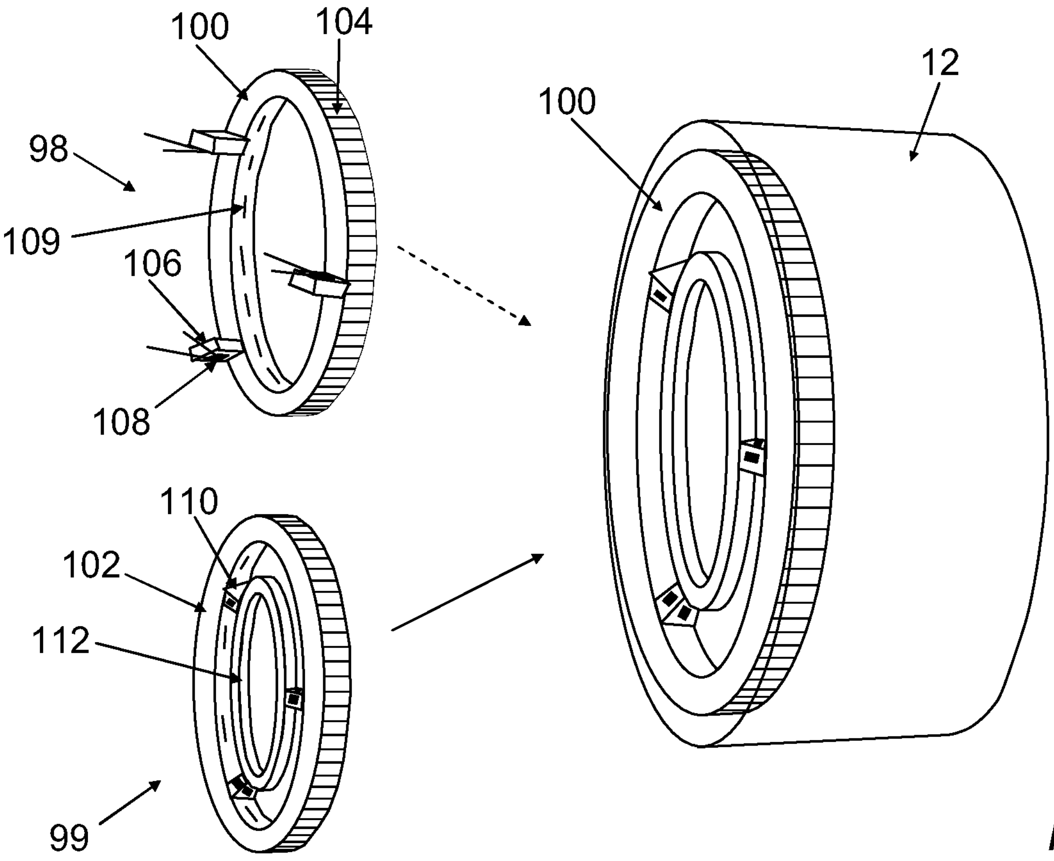
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Fig. 8

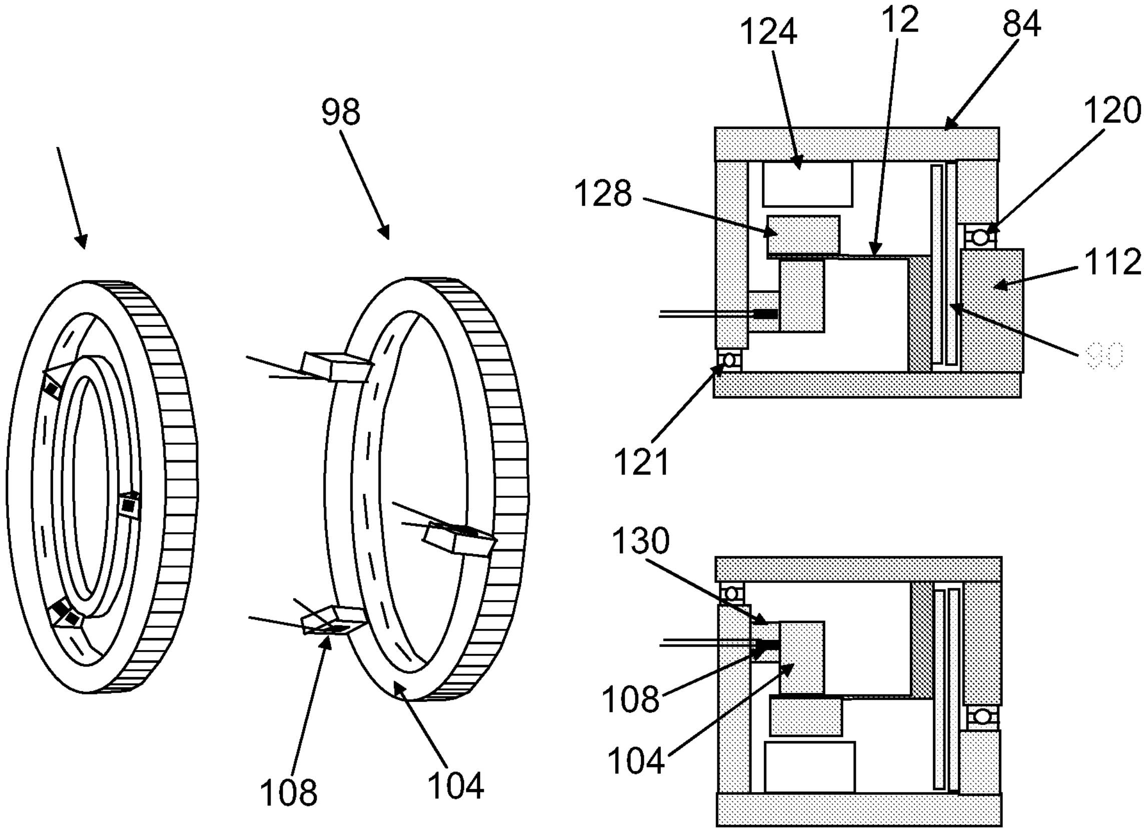
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Fig. 9

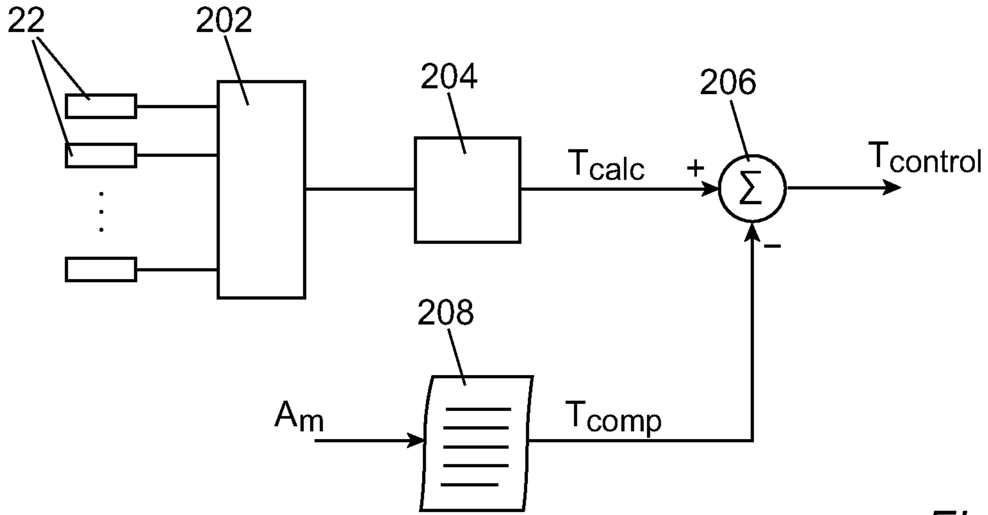
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Fig. 10

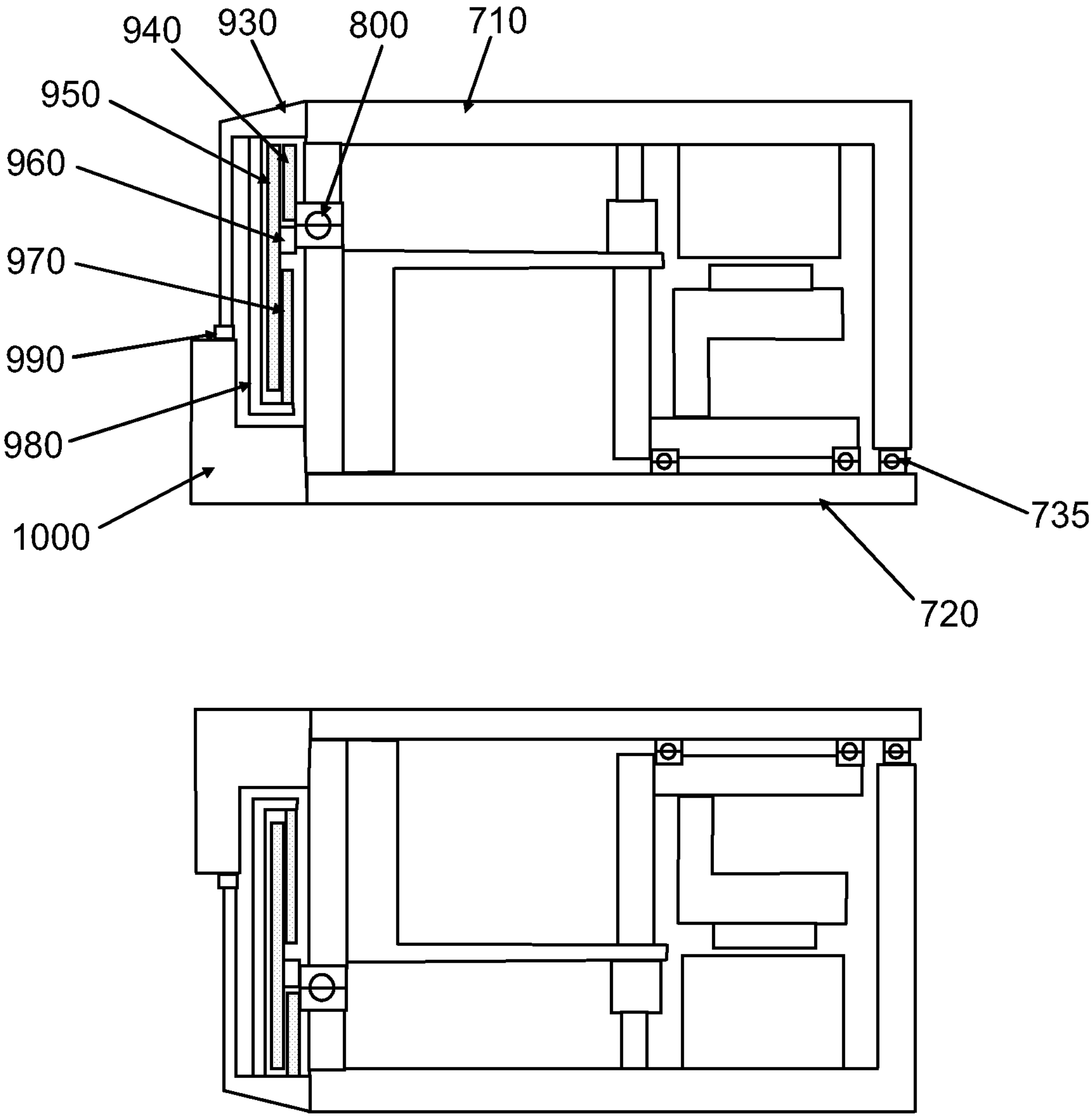

Fig. 11

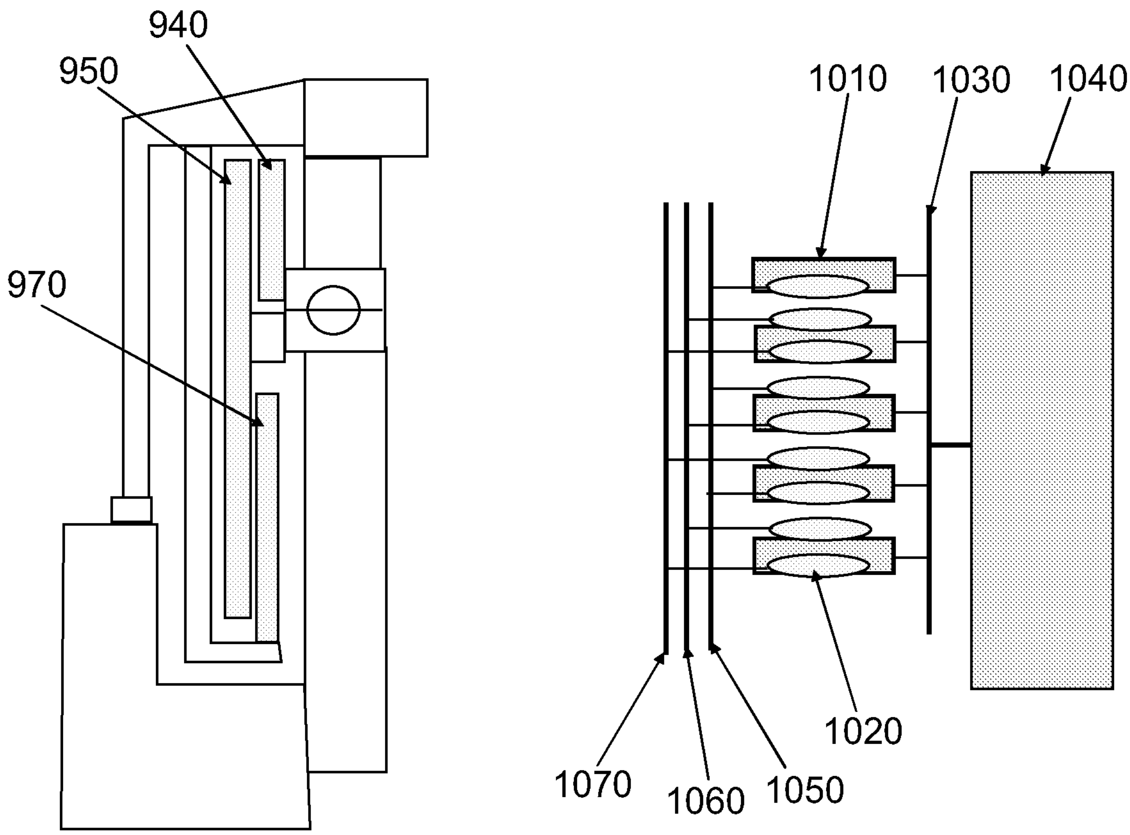

Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/057037

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L3/10 G01L3/14 F16H49/00 B25J9/10 F16H55/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01L F16H B25J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 172 774 A (MELROSE DAVID R [US]) 22 December 1992 (1992-12-22) abstract figures 1,2 column 2, line 22 - column 3, line 9 -----	1-4,9-10
Y	US 4 784 014 A (BRUNS JOACHIM [DE] ET AL) 15 November 1988 (1988-11-15) abstract figure 1 column 1, line 54 - column 2, line 32 -----	1-4,10
Y	US 3 496 395 A (NEWELL HAROLD R) 17 February 1970 (1970-02-17) abstract figures 1-3 column 2, lines 23-57 -----	1-4,9

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 February 2010	10/03/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Nelva-Pasqual, F

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2009/057037

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